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An experimental study of the physiological effects of chain saw operation

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ABSTRACT This experimental study was designed to determine whether a combination of noise and vibration produced more pronounced changes in temporary shifts of finger skin temperature and temporary threshold shift (TTS) of hearing than those resulting from exposure to either stress alone. Nineteen healthy subjects were exposed to six different combinations of vibration, noise, and handle holding by using a chain saw for a pre-determined time. The mean value of normalised finger skin temperature decreased much more when the subjects operated a chain saw at high speed (exposure 1) than when they operated the chain saw with the noise isolated by double hearing protection (exposure 2). In five of the 14 subjects significantly larger TTS values at 4 kHz were observed in the former condition (exposure 1) compared with the values obtained when they stood beside someone else operating a chain saw (exposure 3). The results of this study suggest that noise may play a part in inducing the constriction of the peripheral vessels seen with local exposure to vibration, and that hand-arm vibration may produce an additive effect on the noise induced TTS.

Workers exposed to vibration are usually also exposed to excessive engine noise. In laboratory experiments noise has been shown to enhance the vasoconstriction produced by vibration, probably by activating the sympathetic nervous system.[1] Workers exposed to vibration for prolonged periods develop vasospastic symptoms in the peripheral circulation. Recent reports indicate that simultaneous exposure to vibration from hand held tools and to noise acts synergistically to produce a noise induced permanent threshold shift.[2–4] It is necessary, then, to take account not only of vibration factors but also of noise factors, working conditions (work posture, handle grasping power), and ambient temperature when we study the physiological effects of chain saw operation. It is impossible to separate the effects of these working factors from those of vibration stress since vibration is almost always associated with these factors under actual working conditions. On the other hand, some have pointed out that always to treat them as a combined environmental influence may actually be confusing the whole picture of the health hazards of vibration.[5] The purpose of the present study was to determine whether or not a combination of noise and vibration produced more pronounced changes in the temporary shifts of finger skin temperature and temporary threshold shifts of hearing than those resulting from exposure to either stress alone.

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Subjects and methods

SUBJECTS

The 19 healthy adult men were all volunteers and had not previously been exposed to the environmental factors involved (students, researchers, and clerks). Their ages ranged from 20 to 60 (20–39 (11), 40–60 (8)).

OBSERVATION METHODS

Finger skin temperature was measured on the left third finger by thermocouple (Takara thermister model-D925, accuracy ± 0·02°C) throughout the experiments.

Hearing threshold values were determined with a Békésy type audiometer (Nagashima Medical Institute, model A-60-B) in a test room (sound level < 35 dBA). Before each exposure, the thresholds at 1000, 2000, 3000, 4000, and 6000 Hz were measured. The measurement of postexposure thresholds began 30 seconds after cessation of exposure and lasted for 30 seconds at each of the test frequencies. Temporary

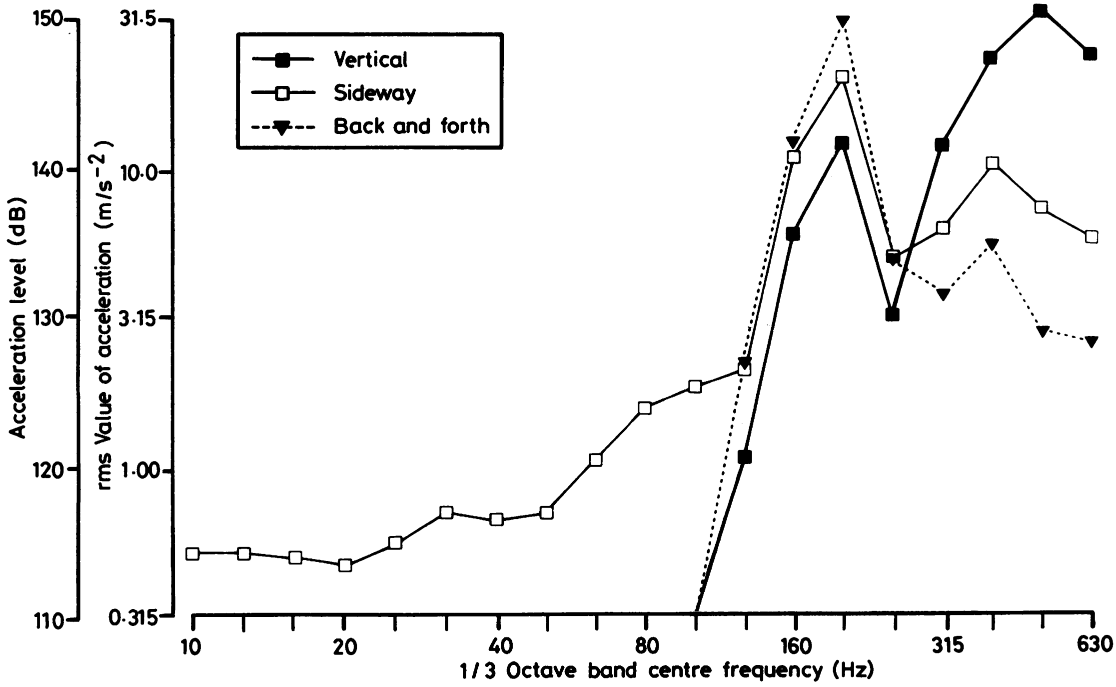

Fig 1 *Vibration spectrum of chain saw handle (Shingu SP500D) analysed in ⅓ octave band.*

threshold shifts (TTS) at each frequency were obtained by subtracting the pre-exposure from the postexposure threshold.

EXPERIMENTAL DESIGN

The study was carried out as a factorial experiment of combinations of vibration, noise, and handle holding: six treatment combinations were therefore used.

Exposure 1—Subjects operated a chain saw at a high working speed (sound level 105 dBA) without actually cutting.

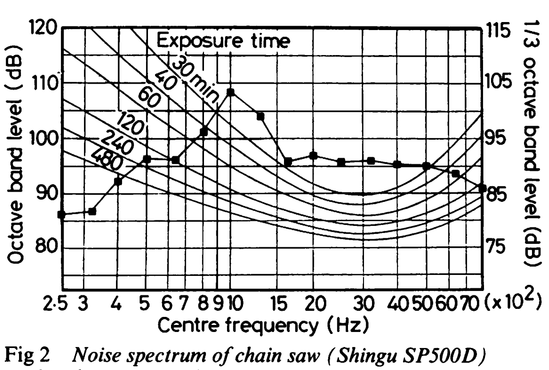

Fig 2 *Noise spectrum of chain saw (Shingu SP500D) analysed in ⅓ octave band including curves of permissible criteria for steady state noise exposure recommended by Japan Association of Industrial Health.*

Exposure 2—Subjects operated a chain saw with the noise isolated by double hearing protection[6] (ear plug (DESI DAMP) and ear muff (Bilson No 2318)). Attenuation in dB at 4 kHz was 41·9 ± 2·1 for the ear plug and 42·0 ± 3·2 for the ear muff (tested in accordance with ANSI S3. 19–1974).

Exposure 3—Subjects stood beside someone operating a chain saw.

Control 1—Subjects held a chain saw that was not working (temperature of chain saw handle ranged from 20° to 24°C).

Control 2—Subject held a chain saw that had just been turned off (temperature of chain saw handle ranged from 27° to 30°C).

Control 3—Subjects stood without any load.

The time profile of a single experiment consisted of a 30 minute pre-exposure period followed by five exposure periods each lasting two minutes immediately followed by a 30 second break, and finally a postexposure (recovery) period of 8·5 minutes in exposure 1–3 and five minutes in control 1–3. The experiments were conducted at a room temperature between 20° and 24°C in the autumn and spring between 1800 and 2000. The subjects wore street clothing during the experiments.

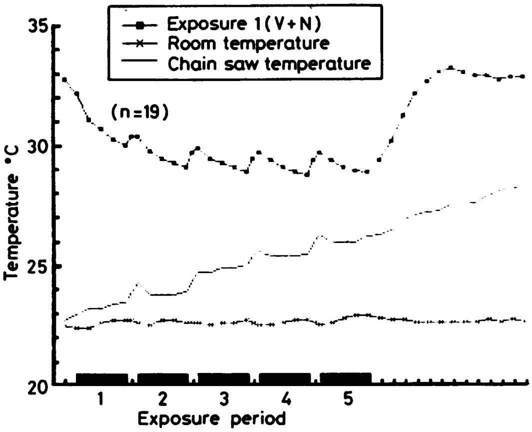

Fig 3 *Changes in finger skin temperature, room temperature, and temperature of chain saw handle in exposure 1.*

VIBRATION AND NOISE OF CHAIN SAW

Subjects were exposed to noise and vibration from a chain saw (Shingu SP500D) under model exposure conditions. The vibration was measured as the root mean square value in metres per second,[2] (rms in m/sec,[2] dB: 0 dB ref 10^{-6}m/sec^{2}) having a Rion triaxial accelerometer mounted rigidly on the handle. The signals from the accelerometer were then amplified and tape recorded and the recorded signals were analysed into one third octave band levels in the frequency range between 5 and 1000 Hz; the results are shown in fig 1.

The noise was measured with a precision sound level meter (Rion NA 60) with octave filters that met the demands of the IEC standard. A condenser microphone was located near the ear of the subjects during model work (fig 2). In addition, the vibration level at 105 dBA was monitored during the experiment. The vibration level of a loaded left handle was 153·5 dB (X–axis), 149 dB (Y–axis), and 151·5 (Z–axis) during the chain saw operation at a sound level of 105 dBA.

ANALYSIS OF THE DATA

The skin temperature obtained during the exposure and postexposure periods were normalised by the values obtained in pre- and postexposure periods. The statistical significance of the differences between paired means were determined with a two tailed *t* test.

Results

CHANGES OF FINGER SKIN TEMPERATURE

The changes in room temperature, temperature of the chain saw handle, and the finger skin temperature during exposure 1 are shown in fig 3. The finger skin temperature decreased gradually with cyclic changes corresponding to each exposure and break period. On the other hand, the temperature of chain saw handle gradually increased with continuous engine operation. Therefore, the handle holding condition is an important factor to be analysed. Figure 4 shows the changes in the normalised finger skin temperature during three different handle holding conditions. The skin temperatures in control 2 were greater than 100% in every holding period due to heat conductance; those in control 1, however, decreased gradually and continuously during the handling period. The changes of skin temperature in control 1 contrasted significantly with those in control 2. It is necessary to take these results into consideration when evaluating changes in finger skin temperature in exposures 1 and 2.

In fig 5 and the table the changes in the normalised finger skin temperature in exposures 1, 2, and 3 are shown. The mean value of the finger skin temperature decreased much more in exposure 1 than in exposure 2 with increased exposure time; however, there was no

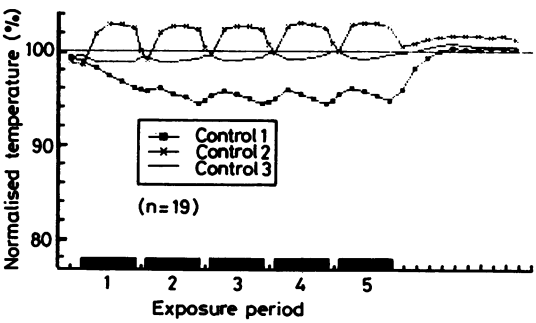

Fig 4 *Changes in normalised finger skin temperature in controls 1, 2, and 3.*

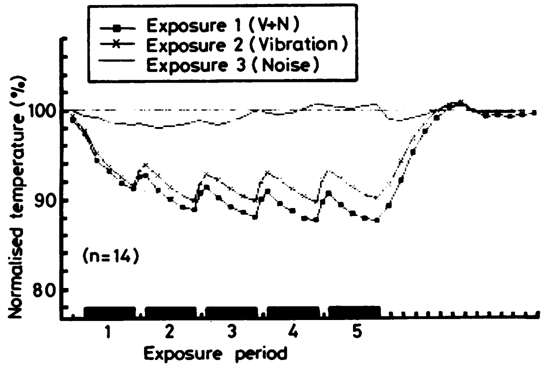

Fig 5 *Changes in normalised finger skin temperature in exposures 1, 2, and 3.*

Changes in normalised finger skin temperature in exposures 1, 2, and 3

Experimental period	Seconds	Experimental condition: Exposure 1 V + N	Exposure 2 V	Exposure 3 N
Pre-exposure period		99·0 (1·3)	99·4 (0·8)	100·0 (0·6)
Exposure period 1	0	97·5 (1·3)	97·8 (0·8)	99·5 (0·7)
	30	94·5 (2·2)	95·2 (1·7)	99·2 (0·8)
	60	93·2 (2·7)	93·7 (2·2)	98·8 (1·1)
	90	92·0 (2·5)	92·6 (2·8)	98·6 (1·3)
	120	91·2 (2·4)	91·6 (2·9)	98·5 (1·9)
	135	92·6 (2·4)	93·4 (2·1)	98·6 (1·9)
Exposure period 2	150	92·8 (2·7)	94·0 (1·5)	98·4 (1·8)
	180	91·1 (3·3)	92·7 (2·1)	98·1 (2·2)
	210	90·1 (3·5)	91·5 (2·2)	98·3 (2·6)
	240	89·3 (3·4)	90·6 (2·3)	98·5 (2·9)
	270	88·9 (3·5)	90·0 (2·6)	98·8 (3·1)
	285	90·8 (3·5)	91·9 (2·0)	99·0 (3·2)
Exposure period 3	300	91·5 (3·6)	93·0 (2·1)	98·7 (3·3)
	330	90·2 (3·9)	92·3 (2·6)	98·4 (3·4)
	360	89·3 (3·4)	91·2 (2·8)	98·7 (3·6)
	390	88·6 (3·3)	90·5 (2·9)	99·2 (3·5)
	420	88·1 (3·1)	89·9 (3·1)	99·9 (3·2)
	435	90·1* (3·5)	92·1 (2·5)	100·0 (3·0)
Exposure period 4	450	90·9* (3·7)	93·1 (2·5)	99·7 (2·8)
	480	89·6* (3·8)	92·3 (3·1)	99·6 (2·5)
	510	88·7 (3·8)	91·2 (3·2)	99·7 (2·5)
	540	87·9 (4·0)	90·5 (3·3)	100·2 (2·3)
	570	87·7 (3·7)	89·7 (3·4)	100·7 (2·2)
	585	89·7* (3·7)	92·3 (2·8)	100·8 (2·2)
Exposure period 5	600	90·7* (3·8)	93·4 (2·9)	100·6 (2·2)
	630	89·4* (3·7)	92·4 (3·2)	100·4 (2·1)
	660	88·4* (3·9)	91·4 (3·2)	100·3 (2·0)
	690	88·0* (3·8)	90·6 (3·3)	100·6 (1·8)
	720	87·8* (3·7)	90·3 (3·2)	100·7 (1·6)
Post exposure period	750	89·4* (3·9)	91·7 (2·6)	99·1 (1·7)
	780	92·3* (4·3)	94·4 (3·0)	99·0 (1·8)
	810	95·5 (3·9)	97·0 (3·1)	99·3 (1·6)
	840	97·7 (3·1)	98·7 (2·7)	99·6 (1·8)
	870	99·3 (2·6)	100·0 (2·5)	100·0 (1·7)
	900	100·2 (2·4)	100·7 (2·2)	100·6 (1·8)
	930	100·8 (2·5)	101·1 (2·2)	100·8 (1·7)
	960	100·1 (2·2)	100·0 (2·3)	99·9 (1·7)
	990	99·5 (2·1)	99·9 (2·2)	99·9 (1·2)
	1020	99·6 (1·9)	100·0 (2·2)	99·9 (1·2)
	1050	99·4 (2·1)	100·0 (2·2)	99·9 (0·8)
	1080	99·6 (2·2)	100·0 (2·3)	100·0 (0·9)
	1110	99·8 (2·5)	100·1 (2·7)	100·0 (1·1)
	1140	99·6 (3·0)	100·1 (2·8)	100·0 (1·1)
	1170	99·8 (3·1)	100·1 (3·0)	99·8 (1·2)
	1200	99·7 (3·2)	99·9 (3·2)	99·7 (1·3)
	1230	99·8 (3·5)	99·7 (3·3)	99·6 (1·3)

*$p < 0·05$ (exposure 1 *v* exposure 2).
Mean value (SD).

significant difference between the two groups in the early stages of exposure. The slight decrease in finger skin temperature observed during the early stage of noise exposure should be noted (exposure 3). Of the seven subjects who showed a remarkable decrease in finger skin temperature during exposure 1, five also showed a decrease during exposure 3 (fig 5). Also, seven subjects without any clear change of finger skin temperature during exposure 1 did not show a decrease during exposure 3.

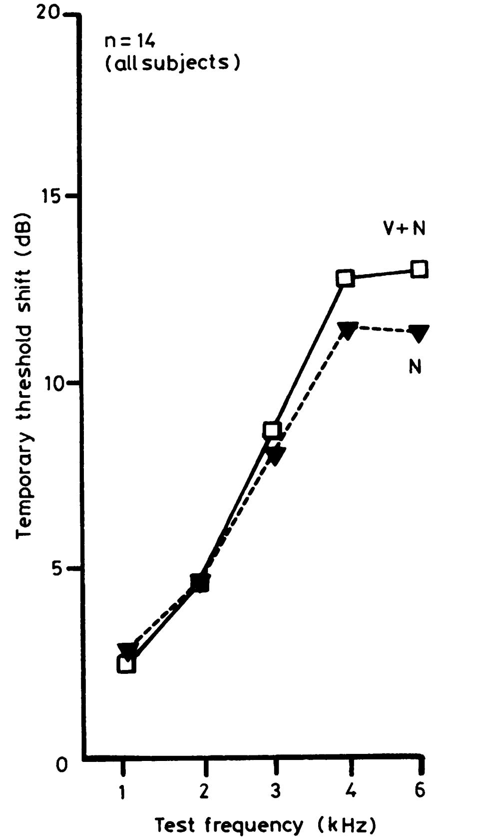

Fig 6 *TTS of hearing in exposure 1 (V + N) and 3 (N) in 14 subjects.*

TEMPORARY THRESHOLD SHIFT (TTS) OF HEARING

In 14 of the subjects examined there were no significant differences in the mean values of TTS between exposure 1 and exposure 3, as shown in fig 6. Nevertheless, five subjects showed significantly larger TTS values in the high frequency region (fig 7). As shown in fig 7, values 2·9 dB larger ($p < 0·1$) at 3 kHz and 5·9 dB larger (p 0·01) at 4 kHz TTS were observed in exposure 1 by comparison with the values in exposure 3.

Discussion

In an earlier study it had been observed that there was a significantly greater hearing loss in chain saw oper-

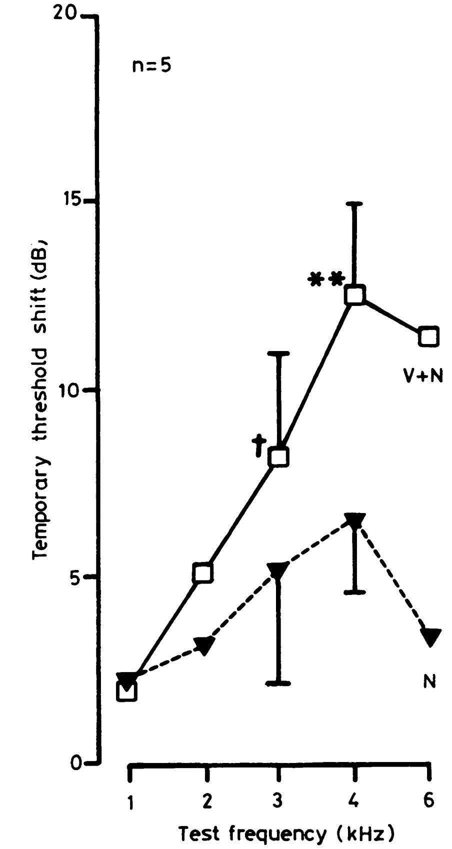

Fig 7 *TTS of hearing in exposures 1 (V + N) and 3 (N) in five subjects who showed larger TTS values in exposure 1 than in exposure 3.*

ators with vibration induced white finger (VWF) than in those without VWF in the five to nine years exposure group.[7] Pyykkö *et al* pointed out that a statistically significant hearing difference was found between lumberjacks with VWF and those without.[2] Recently Iki *et al* reported a similar result for 37 men with Raynaud's phenomenon.[3 4] In their research a control group was chosen from those unaffected whose ages and operating hours for the tools were almost the same as those of the cases with white finger. These cases had higher median hearing thresholds than the controls at 4000 and 8000 Hz, and had more advanced types of noise induced hearing loss than the controls. In this study it was suggested that noise may play a part in inducing changes in the peripheral circulation after local exposure to vibration and that hand-arm vibration may affect the temporary threshold shift additively with noise exposure. Pyykkö suggested that the proposed aetiological mechanism for noise induced permanent threshold shift (NIPTS) may be similar to that proposed for VWF: chronic over excitation of the sympathetic nervous system.[8]

Although many investigators have observed the deleterious effects of noise on the cochlea,[9-11] the actual mechanism(s) of temporary threshold shift (TTS) and permanent threshold shift are still obscure. In addition to the mechanical theory mentioned earlier, the other mechanisms discussed frequently are metabolic exhaustion, vascular changes, and ionic changes in the cochlear ducts (endo- and perilymph). In attempting to evaluate the results obtained in epidemiological studies, we have become interested in the metabolic exhaustion of the stimulated cells and the changes in vascular supply during exposure to noise.

No other organ of the body possesses such a number of distinct, specialised, microvascular networks as the inner ear.[12] The blood circulation of the inner ear depends entirely on the blood supplied by the vertebrolbasilar artery system.[13] This suggests that under normal circumstances the circulation patterns found in the inner ear are similar to those observed in the brain, and are haemodynamically stable. By contrast with skin circulation, in which there is a limited ability for control by autoregulation, the circulation in the inner ear shows prominent autoregulation exerted through capillary resistance, which is determined by local conditions and by the autonomic nervous system.[14] According to recent morphological studies the inner ear has a dense adrenergic innervation system.[15-17] There is also a suggestion that any effect after sympathetic nervous system intervention will only be clearly shown in a stressed organ.[18]

During exposure to noise, reduction of the oxygen tension in the cochlea has been reported.[19 20] This phenomenon has been interpreted as reflecting the reduction in cochlear blood flow or excessive oxygen consumption, or both.[21] Concerning this reduction of oxygen tension and blood flow, Maass *et al*, after experimenting with a unilateral acute upper cervical sympathectomy in a cat, suggested the participation of the sympathetic nervous system.[22] In the conscious rabbit with unilateral sympathectomy Hultcrantz reported a 25% difference in the cochlear blood flow between the two cochleas even before exposure to noise.[23] Sita observed the effects of intense noise on the dynamic changes in endolymphatic potential (EP) under asphyxic anoxia, and obtained evidence that the activation of the sympathetic nervous system in response to intense noise induced vasoconstriction in the cochlea.[24] Muchnik *et al* showed the possibility that emotional stress alone could affect hearing if severe enough or if it lasted long enough, and explained this noxious effect on the ear by the high level of blood catecholamines and excessive cochlear sympathetic innervation.[25] Thus Pyykkö's hypothesis is fairly reasonable—that is, the sympathetic nervous outflow may disturb cochlear blood flow during exposure to noise.

The synergism of noise and vibration suggest a common mechanism as stressors. Furthermore, local vibration may induce hypersensitivity to catecholamine in local median muscular layer as suggested by Azuma *et al.*[26] Matoba *et al* observed that chain saw work might have an influence on hormonal effects including those of catecholamines.[27] And peripheral circulation is also affected by handle grasping posture. The activation of the sympathetic nervous system may override the autoregulation of the inner ear and fingers by disturbing compensatory changes in the peripheral circulation during periods of high local energy demand. On the other hand, there are fairly large individual variations in the effect of sympathetic nervous system on the peripheral circulation. In this study there was a noise induced decrease of finger skin temperature in half the subjects, and TTS was more noticeable after the addition of exposure to vibration in five of the 14 subjects.

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